EVIDENCE RELEVANT TO THE LIFE ON MARS DEBATE. (1) ^{14}C RESULTS.

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Abstract: The martian meteorite EET A79001 contains, in localised concentrations, a relatively high proportion of organic materials, equivalent to about 1000 ppm carbon (compared to a maximum of 200 ppm which could be ascribed to terrestrial contamination). The organic compounds are associated with carbonate minerals, for which arguments have been made to substantiate a pre-terrestrial (i.e. martian) origin. However, measurements of ^{14}C have cast aspersions on the provenance of the carbonates, suggesting instead a terrestrial origin. Herein we show that these results are misleading and conclude that the minerals are indeed martian. What we are left with now are putative martian organic materials with a carbon isotopic composition that is very similar to that of the Earth's biomass. More importantly there is a large isotopic difference between the carbon in the organic fraction compared with that of martian atmospheric carbon dioxide (and subsequently formed carbonates). It is tempting to equate this with the effect of vital processes on Earth. For this to be true it would be necessary to accept that biological activity had occurred on Mars in the very recent past (i.e. between 0.6×10^6 and 0.18×10^9 years ago).

In 1989 Wright et al. [1] showed that the martian meteorite EET A79001 (hereafter E79) contained indigenous organic materials. As an extension of this work, another martian meteorite (ALH 84001, hereafter A84) was also shown to contain organic compounds [2] and more recently it has been proposed that the sample may contain biological microfossils [3], the implication being that there was once life on Mars. The rest is history.

To assess the likelihood of the long-term existence of life on Mars (prior to a space mission, which could return samples to Earth for study) it would be appropriate to study martian meteorites of different ages. In this regard A84 might be considered to represent an end-point, having an age almost as old as the planet itself [4]. Nakhlites and chassignites have intermediate ages of around 1.3×10^9 years [e.g. 5]. In contrast, shergottites have ages that could be as young as 0.18×10^9 years [e.g. 6], but this remains a controversial subject [7]. Regardless, in order to investigate the possibility of recent life on Mars it is necessary to contemplate looking for evidence in the shergottites. At this point it is necessary to inject some caution into the approach. Martian meteorites are hardly ideal samples within which to look for signs of life (although clearly this becomes an almost philosophical issue since our expectations and definitions of life revolve around what is available for us to study on Earth). Since the meteorites represent relatively fresh samples of igneous rocks, produced by volcanic activity either at high- or low-levels within the martian crust [e.g. 8], then from just their primary features it is apparent that they could not record any evidence of life. Rather, it is the subsequent history of the samples that are investigated - i.e. secondary events such as weathering, hydrothermal activity, atmospheric exposure etc. In this regard the available martian meteorites have been affected to lesser or greater extents - A84 records one of the most extensive episodes of secondary processing. However, it should be pointed out that the carbonates have been variously interpreted as low-temperature, hydrothermal products [9], which *could* preserve evidence of life (if it were there in the first place), or rapidly deposited, high-temperature minerals produced by an impact-driven process [10], within which we would not expect to find fossilised life.

Another meteorite that contains rather obvious evidence for secondary activity is E79. On the basis of stable isotopic compositions the carbonates in this sample would appear to be low-temperature products [11,12]. Indeed, for E79 there are currently no disagreements regarding the formation temperatures of the carbonates. Since the crystallisation age of E79 is 0.18×10^9 years [e.g. 6] and the meteorite was ejected from Mars about 0.6×10^6 years ago [13], it is reasonable to assume that the low-temperature activity that imparted the carbonates took place, geologically speaking, within the recent past. It has already been shown that E79 contains organic materials in amounts high enough to have allowed measurement of their collective stable carbon isotopic composition [1]. However, some doubt has been cast on the results from ^{14}C determinations of the carbonates [14], with which the organic materials are associated. On the basis of joint ^{13}C/^{12}C (d^{13}C) and ^{14}C/^{12}C measurements (as well as ^{14}C/^{12}C alone) it has been suggested that between 57 and 95% of the carbon in the carbonates of E79 could be of recent origin. There could be two reasons for this [14]; either the carbonates in E79 are largely terrestrial weathering products, or they may be indigenous but have suffered from isotopic exchange with terrestrial atmospheric CO_2. In either case, the carbonates in E79 *appear* to be of such questionable origin that defining an unambiguous origin for the associated organic materials seems impossible. We think it appropriate to reappraise the ^{14}C data.

It can be shown that on a plot of carbon content versus ^{14}C (expressed as Fm) samples 10, 12, 17 and 18 (from ref. 14) appear to define a trend, i.e. decreasing carbon content correlating with an increase in ^{14}C. This suggests mixing between a modern end-member (a variable quantity in the range 20-80 ppm C, with Fm ~1) and one with low ^{14}C. Note that sample 4 (from ref. 14) does not adhere to this trend - however, this was treated with relatively strong HNO_3 (0.8N versus 0.06-0.07N for samples 10 and 17) which could conceivably have dissolved some mineralogical components liberating cosmogenic ^{14}C and thereby giving an enhanced, and entirely erroneous, value of Fm (see ref. 15 for a discussion of this phenomenon). In trying to assess the nature of the low-^{14}C end-member it is worth pointing out that sample 12 (which was treated with 100% H_3PO_4) also has a d^{13}C measurement, which at +3.1‰ is somewhat lower than values from E79,239 (+6.8 to +9.7‰; refs. 11,12). We can be confident, therefore, that the end-member is *not* a modern Antarctic weathering product since these have d^{13}C values of +7.9‰ [16] to +4.3‰, with Fm values of about 1.0-1.2 [17]. In contrast, if we assume that the end-member is present-day atmospheric CO_2 (d^{13}C of -7‰, Fm=1.1) then a mixing calculation shows that the martian carbonates in sample 12 have d^{13}C of +13.5±2.5‰. This is entirely consistent with carbonates contained *within* shock-produced glass in E79 (d^{13}C of +11.1±2.0‰ [18]).

Thus, we do not accept that the ^{14}C data are evidence of widespread distribution of Antarctic weathering products in E79. The question of carbon isotope exchange is interesting, but also irrelevant in the present context (since this could influence the isotopic composition of carbonates without affecting the overall carbon budget). In any case we think this an unlikely effect since it would be anticipated that a similar process would have perturbed the isotopic system of the genuine Antarctic weathering products, which it has not [17]. The notion of ^{14}C exchange would seem to undermine the usefulness of this parameter as an age-dating tool, which is surely not in question.

We are left with the same conclusion as in 1989 [1] - whatever process added the carbonates to E79 also deposited organic compounds. We know that this was a low-temperature process involving aqueous fluids. A good case has already been made for the carbonates to be martian; this is now reinforced by a dismissal of the misleading ^{14}C data. If life was once present on Mars [3] we would have to ask whether life was active at the time of carbonate deposition in E79 ($0.6x10^6$ to $0.18x10^9$ years). In other words, during the span of the Cenozoic and Mesozoic eras on Earth, a time when dinosaurs lived and died, the first flowering plants evolved, and the first hominids appeared.

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